CLAIMS

What is claimed is:

1. A method of managing distortion in a digital communications transmitter in which at least a portion of said distortion is introduced by analog-transmitter components, said method comprising:

obtaining a forward-data stream configured to convey digital information;

training a linear predistorter to compensate for linear distortion introduced by said analog-transmitter components; and

training a nonlinear predistorter to compensate for nonlinear distortion introduced by said analog-transmitter components.

2. A method as claimed in claim 1 wherein:

said linear predistorter comprises a first equalizer, and said nonlinear predistorter comprises a second equalizer;

said linear-predistorter-training activity comprises operating said first equalizer in an adaptive mode to compensate for said linear distortion; and

said nonlinear-predistorter-training activity comprises operating said second equalizer in an adaptive mode to compensate for said nonlinear distortion.

3. A method as claimed in claim 2 wherein:

said linear-predistorter-training activity operates said first equalizer in a non-adaptive mode when said second equalizer is operated in said adaptive mode; and

said nonlinear-predistorter-training activity operates said second equalizer in a non-adaptive mode when said first equalizer is operated in said adaptive mode.

4. A method as claimed in claim 1 wherein said nonlinear-predistorter-training activity occurs after said linear-predistorter-training activity.

5. A method as claimed in claim 1 wherein said linear-predistorter-training activity comprises determining filter coefficients for an equalizer which filters said forward-data stream.

6. A method as claimed in claim 5 additionally comprising:

down-converting a feedback signal obtained from said analog-transmitter components using a digital-subharmonic-sampling downconverter to generate a return-data stream; and

processing said return-data-stream to generate said filter coefficients.

7. A method as claimed in claim 6 wherein said processing activity controls one or more estimation-and-convergence algorithms to generate said filter coefficients.

8. A method as claimed in claim 7 wherein said one or more estimation-and-convergence algorithms are responsive to said forward-data stream and to said return-data stream;

said forward-data stream and said return-data stream exhibit forward-error and return-error levels, respectively, with said return-error level being greater than said forward-error level; and

said one or more estimation-and-convergence algorithms are configured to transform increased algorithmic processing time into reduced effective-error level for said return-data stream.

9. A method as claimed in claim 1 wherein said forward-data stream is provided by a peak-reduction section, said analog-transmitter components include a power amplifier which produces a power-amplifier-output signal, and said method additionally comprises:

obtaining an residual value that estimates uncompensated nonlinear distortion introduced by said analog-transmitter components into said power-amplifier-output signal; and

operating said peak-reduction section so that an amount of peak reduction imposed in said forward-data stream is responsive to said residual value.

10. A method as claimed in claim 9 wherein said operating activity increases said amount of peak reduction when said residual value indicates nonlinear distortion exceeding a predetermined amount.

11. A method as claimed in claim 1 wherein:

each of said linear-predistorter-training and nonlinear-predistorter-training activities processes a return-data stream obtained from said analog-transmitter components;

said forward-data stream exhibits a forward resolution; and

said return-data stream exhibits a return resolution less than said forward resolution.

12. A method as claimed in claim 11 wherein said return resolution is at most four bits less than said forward resolution.

13. A method as claimed in claim 1 wherein:

each of said linear-predistorter-training and nonlinear-predistorter-training activities processes a return-data stream obtained from said analog-transmitter components;

each of said linear-predistorter-training and nonlinear-predistorter-training activities implements an estimation-and-convergence algorithm responsive to said forward-data stream and to said return-data stream;

said forward-data stream and said return-data stream exhibit forward-error and return-error levels, respectively, with said return-error level being greater than said forward-error level; and

said estimation-and-convergence algorithm controls a rate of convergence to achieve a predetermined effective return-error level that is less than said return-error level.

14. A method as claimed in claim 1 wherein:

each of said linear-predistorter-training and nonlinear-predistorter-training activities processes a return-data stream obtained from said analog-transmitter components;

each of said linear-predistorter-training and nonlinear-predistorter-training activities implements an estimation-and-convergence algorithm responsive to said forward-data stream and to said return-data stream; and

said estimation-and-convergence algorithm estimates filter coefficients which influence said forward-data and return-data streams, generates an error signal by combining said forward-data and return-data streams, and repetitively revises said

filter coefficients to minimize said error signal and to decorrelate said error signal from said forward-data stream.

15. A method as claimed in claim 1 additionally comprising:

obtaining a return-data stream from said analog-transmitter components;

delaying said forward-data stream to form a delayed-forward-data stream in temporal alignment with said return-data stream;

forming an error signal by combining said delayed-forward-data stream and said return-data stream; and

performing said linear-predistorter-training and nonlinear-predistorter-training activities by implementing an estimation-and-convergence algorithm that converges upon filter coefficients which minimize said error signal.

16. A method as claimed in claim 15 wherein:

said forward-data and return-data streams are complex data streams; and

said delaying activity comprises delaying said forward-data stream to compensate for common mode delay between said forward-data and return-data streams.

17. A method as claimed in claim 15 wherein:

said forward-data stream propagates through said nonlinear predistorter and through said linear predistorter in response to a clock signal; and

said delaying activity delays at least a portion of said forward-data stream by an integral number of cycles of said clock signal and further delays said portion of said forward-data stream by a fraction of a cycle of said clock signal.

18. A method as claimed in claim 1 wherein:

said linear predistorter comprises a first non-adaptive equalizer, and said nonlinear predistorter comprises a second non-adaptive equalizer;

said linear-predistorter-training activity comprises coupling an adaptation engine to said first non-adaptive equalizer to determine filter coefficients for said first non-adaptive equalizer;

said method additionally comprises decoupling said adaptation engine from said first non-adaptive equalizer; and

said nonlinear-predistorter-training activity comprises coupling said adaptation engine to said second non-adaptive equalizer to determine filter coefficients for said second non-adaptive equalizer.

19. A method as claimed in claim 1 wherein:

said analog-transmitter components include a power amplifier which is driven by a power-amplifier-input signal and which produces a power-amplifier-output signal; and

said linear-predistorter-training activity comprises downconverting said power-amplifier-input signal then downconverting said power-amplifier-output signal.

20. A method as claimed in claim 1 wherein said nonlinear-predistorter-training activity comprises

generating a plurality of basis-function-data streams, wherein each basis-function-data stream is responsive to $X(n) \bullet |X(n)|^K$, where $X(n)$ represents said forward-data stream, and K is an integer greater than or equal to one;

estimating filter coefficients for filters that process said basis-function streams;

filtering said basis-function-data streams in said filters to generate a plurality of filtered-basis-function-data streams;

combining said filtered-basis-function-data streams and said forward-data stream; and

repetitively revising said filter coefficients to compensate for said nonlinear distortion.

21. A digital communications transmitter comprising:

a source of a forward-data stream configured to digitally convey information;

a nonlinear predistorter coupled to said forward-data-stream source and configured to generate a nonlinear-predistorted-compensation stream from said forward-data stream;

a combiner coupled to said forward-data-stream source and said nonlinear predistorter and configured to generate a nonlinear-predistorted-forward-data stream from said forward-data stream and said nonlinear-predistorted-compensation stream;

a linear predistorter coupled to said combiner and configured to generate a linear-and-nonlinear-predistorted-forward-data stream, said linear-and-nonlinear-predistorted-forward-data stream being routed to analog-transmitter components; and

a feedback section having an input adapted to receive an RF-analog signal from said analog-transmitter components and an output coupled to said nonlinear predistorter and to said linear predistorter.

22. A digital communications transmitter as claimed in claim 21 wherein:

said analog-transmitter components include a power amplifier which produces a power-amplifier-output signal;

said transmitter additionally comprises a peak-reduction section coupled to said forward-data-stream source and to said feedback section;

said peak-reduction section generates a peak-reduced-forward-data stream so that said nonlinear predistorter and said combiner operate upon said peak-reduced-forward-data stream; and

said peak-reduction section imposes an amount of peak reduction in said peak-reduced-forward-data stream that is responsive to a residual value, said residual value estimating uncompensated nonlinear distortion introduced by said analog-transmitter components into said power-amplifier-output signal.

23. A digital communications transmitter as claimed in claim 22 wherein said peak-reduction section increases said amount of peak reduction when said residual value indicates nonlinear distortion exceeding a predetermined amount.

24. A digital communications transmitter as claimed in claim 21 wherein:

said nonlinear predistorter comprises a first equalizer which operates in an adaptive mode to compensate for nonlinear distortion; and

said linear predistorter comprises a second equalizer which operates in said adaptive mode to compensate for linear distortion.

25. A digital communications transmitter as claimed in claim 24 wherein:

said first equalizer is a first-non-adaptive equalizer configured to be programmed with first-filter coefficients;

said second equalizer is a second-non-adaptive equalizer configured to be programmed with second-filter coefficients; and

said digital communications transmitter additionally comprises an adaptation engine selectively coupled to and decoupled from said first-non-adaptive and second-non-adaptive equalizers and configured to implement an estimation-and-

convergence algorithm which determines said first-filter and second-filter coefficients.

26. A digital communications transmitter as claimed in claim 24 wherein:

said first equalizer operates in a non-adaptive mode when said second equalizer is operating in said adaptive mode; and

said second equalizer operates in a non-adaptive mode when said first equalizer is operating in said adaptive mode.

27. A digital communications transmitter as claimed in claim 21 wherein:

said nonlinear and said linear predistorters selectively operate in respective training modes; and

said linear predistorter operates in its training mode to compensate for linear distortion prior to operating said nonlinear predistorter in its training mode to compensate for nonlinear distortion.

28. A digital communications transmitter as claimed in claim 21 wherein said feedback section comprises a complex-digital-subharmonic-sampling downconverter adapted to receive said RF-analog signal from said analog-transmitter components and configured to provide a complex-return-data stream.

29. A digital communications transmitter as claimed in claim 28 wherein:

said forward-data stream exhibits a forward resolution; and

said complex-return-data stream exhibits a return resolution less than said forward resolution.

30. A digital communications transmitter as claimed in claim 21 wherein:

said feedback section generates a return-data stream;

said digital communications transmitter additionally comprises a programmable delay element coupled between said forward-data-stream source and said feedback section; and

said programmable delay element is configured to produce a delayed-forward-data stream temporally aligned with said return-data stream.

31. A digital communications transmitter as claimed in claim 30 wherein:

said forward-data stream is a complex-forward-data stream, and said return-data stream is a complex-return-data stream;

said programmable delay element is a first programmable delay element that adjusts for common mode delay between said complex-return-data and complex-forward-data streams; and

said digital communications transmitter additionally comprises a second programmable delay element coupled between said forward-data-stream source and said feedback section, said second programmable delay element being configured to adjust for differential mode delay.

32. A digital communications transmitter as claimed in claim 30 wherein:

said forward-data stream propagates through digital said communications transmitter in response to a clock signal; and

said programmable delay element includes an integral section that delays said forward-data stream by an integral number of cycles of said clock signal and includes a fractional section that delays said forward-data stream by a fraction of a cycle of said clock signal.

33. A digital communications transmitter as claimed in claim 30 wherein:

said digital communications transmitter additionally comprises a correlator having inputs coupled to said programmable delay element and to said feedback section; and

said correlator is configured to implement an estimation-and-convergence algorithm to bring said delayed-forward-data stream into temporal alignment with said return-data stream.

34. A method of managing distortion in a digital communications transmitter in which at least a portion of said distortion is introduced by analog-transmitter components, said method comprising:

obtaining a forward-data stream configured to convey digital information;

obtaining an RF-analog signal from said analog-transmitter components;

generating a return-data stream from said RF-analog signal;

implementing a first-estimation-and-convergence algorithm to train a linear predistorter to compensate for linear distortion introduced by said analog-transmitter components; and

after training said linear predistorter, applying a second-estimation-and-convergence algorithm to train a non-linear predistorter to compensate for nonlinear distortion introduced by said analog-transmitter components.

35. A method as claimed in claim 34 wherein said forward-data stream is provided by a peak-reduction section, said analog-transmitter components include a power amplifier which produces a power-amplifier-output signal, and said method additionally comprises:

obtaining an residual value that estimates uncompensated nonlinear distortion introduced by said analog-transmitter components into said power-amplifier-output signal; and

operating said peak-reduction section so that an amount of peak reduction imposed in said forward-data stream is responsive to said residual value.

36. A method as claimed in claim 35 wherein said operating activity increases said amount of peak reduction when said residual value indicates nonlinear distortion exceeding a predetermined amount.

37. A method as claimed in claim 34 wherein said first-estimation-and-convergence and said second-estimation-and-convergence algorithms are each responsive to said forward-data stream and to said return-data stream;

said forward-data stream and said return-data stream exhibit forward-error and return-error levels, respectively, with said return-error level being greater than said forward-error level; and

said first-estimation-and-convergence and second-estimation-and-convergence algorithms are configured to transform increased algorithmic processing time into reduced effective-error level for said return-data stream.

38. A method as claimed in claim 34 wherein:

each of said implementing and applying activities processes said return-data stream;

said forward-data stream exhibits a forward resolution; and

said return-data stream exhibits a return resolution less than said forward resolution.

39. A method as claimed in claim 38 wherein said return resolution is at most four bits less than said forward resolution.

40. A method as claimed in claim 34 wherein:

each of said implementing and applying activities processes said return-data stream;

each of said first-estimation-and-convergence and second-estimation-and-convergence algorithms is responsive to said forward-data stream and to said return-data stream;

said forward-data stream and said return-data stream exhibit forward-error and return-error levels, respectively, with said return-error level being greater than said forward-error level; and

said first-estimation-and-convergence and said second-estimation-and-convergence algorithms each control a rate of convergence to achieve a predetermined effective return-error level that is less than said return-error level.

41. A method as claimed in claim 34 wherein:

each of said implementing and applying activities processes said return-data stream;

each of said first-estimation-and-convergence and second-estimation-and-convergence algorithms is responsive to said forward-data stream and to said return-data stream;

said first-estimation-and-convergence and second-estimation-and-convergence algorithms each estimate filter coefficients which influence said forward-data and return-data streams, generate an error signal by combining said forward-data and return-data streams, and repetitively revise said filter coefficients to minimize said error signal and to decorrelates said error signal from said forward-data stream.